UTILIZATION OF FLY ASH

BY R. E. MORGAN

* * * * * * * * * * Information Circular 7635

UNITED STATES DEPARTMENT OF THE INTERIOR
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R. E. Morgan[1/]

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FOREWORD

The Bureau of Mines receives many requests for information regarding the utilization of fly ash from coal. The term fly ash originated in naming the small, solid particles that are carried out of a fuel-burning furnace by the products of combustion. Although the particles might be considered to fly, they include not only ash particles but particles composed of ash and combustible material in various percentages, even particles of essentially pure carbon. In the Test Code for Dust-Separating Apparatus adopted some years ago by the American Society of Mechanical Engineers, the term "dust" is used as a name for gas-borne solid particles because the term "fly ash" "ignores a fundamental concept that ash contains no combustible." However, to date, fly ash continues to be the more popular term, and it appears to be more suitable for use in the title of this Bureau of Mines information circular.

Fly ash not only accumulates in various parts of the boiler equipment, but most city air-pollution ordinances require that a high percentage of it be caught in special collectors. Satisfactory solutions for utilizing fly ash are important, therefore, not only from the general long-view standpoint of conservation of resources but also of relieving the expense and difficulty of disposing of a relatively great quantity of material.

This paper, prepared for the purpose of answering inquiries coming to the Bureau of Mines on the utilization of coal ash, covers a number of such investigations reported in the technical press.

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GENERAL

This publication presents abstracts of articles and investigations pertaining to the utilization of fly ash. The terms "fly ash" and "flue ash," as used in most of the papers, refer to the ash from pulverized-coal firing collected by electrostatic precipitators or mechanical collectors. Several investigators do not define the material on which they report beyond calling it fly ash, but they probably refer to the fine material resulting from burning pulverized coal. A few of the papers report on investigations involving not only the use of fly ash but boiler slag as well. These can be identified by the title of the articles. Bibliographical information and the abstracts are arranged according to the date the papers were published, with the most recent listed first.

With the continually increasing use of pulverized-coal firing, profitable disposal of the fly ash is becoming a problem of greater importance to many utility and industrial companies. Also, in recent years, the public demand for cleaner air, and the more highly efficient fly-ash collectors available have resulted in the collection of a greater percentage of the fly ash produced. The solution to better utilization of fly ash has, therefore, been the object of research for some years.

Many fly ashes have been found to have good pozzolanic properties. Very fine fly ashes low in carbon content appear to be superior pozzolans. Because of this quality, fly ash in some instances has been used with good results as a replacement for an appreciable percentages of the portland cement in concrete mixes. At the large Hungry Horse Dam construction in Montana, great quantities of fly ash from Illinois are used to replace part of the portland cement in the various concrete mixes. The inclusion of the fly ash in the concrete not only reduces cost but results in an excellent concrete product. Fly ash also has been used as a portion of the fine aggregate in concrete and as an additive to the standard concrete mixes. Other commercial uses for fly ash are in bituminous paving where the material is used as a mineral filler, and it can be used in the manufacture of brick. Mixtures of fly ash and boiler slag in a wide range of ratios processed in standard brick-making equipment have produced brick of good quality that compares favorably with common commercial brick.

Numerous other possible uses for fly ash have been tried in the past or are under investigation at the present time. Among them are: (1) sand blasting; (2) ingredient for foundry cores in some nonferrous foundries; (3) filler for other materials, such as fertilizer, paint, and putty; and (4) substitute for pumice in mechanic's soap.

None of the uses considered has, as yet, provided a market for more than a small percentage of the fly ash collected annually at boiler plants. However, many investigators feel that utilization of the material will be greatly increased in the years ahead.

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The transportation and handling of fly ash are important considerations in developing outlets for material. It is ordinarily inadvisable to convey dry, bulk fly ash in open cars or trucks because the windage loss can be high, and the lost material pollutes the surrounding atmosphere. For long-distance hauling the enclosed-type hopper-bottom cars commonly used for transporting cement are desirable. If cost is not a prohibiting factor, the dry material can be bagged before shipment, and use of other types of rolling equipment for transportation is then practicable. After it has compacted in transit, bulk fly ash can be unloaded quickly by using vibrators or pneumatic unloading equipment.

The disposal of cinder or coarse ash resulting from high-temperature combustion of coal is not as serious a problem as is the disposal of fly ash, particularly in built-up areas. Cinder is widely used as an aggregate for concrete, as a fill for low land, and as an underbase for some types of pavement. Precast masonry shapes of various kinds widely used in building construction are manufactured from cinder concrete. For these products the cinders are crushed, intimately mixed with cement and water, and molded under pressure. Sifted coal ash long has been used by homeowners, truck gardeners, and others to improve the physical properties of heavy clay soils, thereby promoting friability and drainage and making cultivation easier. The amount of ash to be used depends on the soil conditions and the type of crop to be grown.

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1. PALMIERI, M. Fly Ash - A Pozzolanic Material of Great Usefulness. Concrete, vol. 59, No. 6, June 1951, pp. 20-22.

Portland cement is defined as a mixture of mainly two chemical compounds, with small amounts of three or four others. Tricalcium silicate and dicalcium silicate are the main compounds. In contact with water, the silicates hydrate, liberating lime. Pozzolans tend to fix, chemically or physically, the free lime. The writer regards fly ashes high in silica and low in carbon as the foremost pozzolans.

Graphs are presented illustrating the comparative compressive strength of straight and blended portland cement and of mixes in which the fly ash replaces the cement, compared with mixes where the fly ash is simply an admixture. The curves show the greater strength of blended mixes over straight portland cement and the superiority of fly ash as a substitute for portland cement over fly ash as an admixture. The fly ash used in these tests was treated with alkalies according to a thermic process described in United States Patent 2,140,850.

The greater resistance to sodium sulfate attack of a mix containing fly ash also is shown. Palmieri points out the importance of this factor in the selection of a concrete mix for structures subject to chemical attack, especially for maritime work.

2. LENHART, WALTER B. Producing Sand and Gravel Aggregates for Hungry Horse Dam. Rock Products, vol. 54, No. 2, February 1951, pp. 98-105.

This article discusses the use of fly ash at this project, as well as the production and preparation of sand and gravel aggregates. A typical analysis of the fly ash, as supplied, is:

	Percent
SiO_2	46.7
Al_2O_3	20.1
MgO	1.1
SO_3	2.7
Ignition loss	3.4
H_2O	.2

It is stated that the fly ash is kept separate throughout all handlings. The loss in handling between railhead and place of use is around 3.5 percent. Portland-cement loss is about 1.6 percent.

Some of the basic mixes used at the dam are as follows: In the tabulations the sand percentage is on the total aggregate weights and the percentage of the coarse aggregate is based on the remainder:

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Interior or mass concrete

	lb. per cu. yd.
Cement	188
Pozzolan (fly ash)	90
Water	155
Aggregate	3,653
Admixture (Protex)	225 gm.

	Percent
Sand	23
3/4-in	22.5
1-1/4-in	22.5
3-in	30
6-in	25

Exterior concrete

	lb. per cu. yd.
Cement	282
Pozzolan (fly ash)	90
Water	170
Aggregate	3,535
Admixture (Protex)	300 gm.

	Percent
Sand	22
3/4-in	25
1-1/4-in	25
3-in	25
6-in	25

Strength tests on these types of concrete are:

Interior concrete (p.s.i.-May 1950)

	3-day	7-day	28-day	90-day
Maximum	940	1,640	3,170	5,150
Average	660	1,170	2,480	3,960
Minimum	420	740	1,600	2,690

Exterior concrete (p.s.i.)

	3-day	7-day	28-day	90-day
Maximum	1,570	2,620	4,510	6,540
Average	1,410	1,870	3,680	5,230
Minimum	610	1,330	2,780	4,020

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In the interior concrete, the weight of fly ash represents 32.4 percent replacement of portland cement. The weight of fly ash in the exterior mix replaces 24.2 percent of cement. Protex is used as an air-entraining agent.

Note: The part of the article pertaining to the preparation of aggregates is not abstracted.

3. MAJOR, W. S. Fly-Ash Disposal Can Be Profitable. Ind. and Power, vol. 59, No. 2, August 1950, pp. 78-81.

Major discusses the properties of fly ash, methods of handling and transporting it, and some of the uses covered in research and the results of these studies. Table 1 gives the results of a survey made in 1948-1949 to determine what utility and industrial plants do with the collected fly ash. A bibliography of ash-disposal literature is presented at the end of the article.

TABLE 1. - Transportation and end uses of fly ash

Method of transporting	Utility or industrial plant																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bulk:																			
RR cars		X			X			X											
Trucks	X		X			X	X			X	X						X	X	
In bags:																			
RR cars			X		X														
Trucks			X		X														
Sluice or pumped				X			X	X				X		X	X				X
End use of fly ash																			
Fill or accumulate	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Dumped in ocean															X				
Mineral filler		X																	
Abrasive		X																	
In asphalt paving[1]		X														X			
Admixture in concrete[1]		X													X				
Pozzolanic material[1]					X														
Bricks[1]								X											
Building blocks[1]								X											
Cinder blocks[1]											X								
Concrete pipes[1]					X						X								
RR grouting					X						X								

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TABLE 1. - Transportation and end uses of fly ash (Cont.)

Method of transporting	Utility or industrial plant																
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Bulk:																		
RR cars												X						
Trucks	X			X	X		X	X		X	X				X		X	X
In bags:																		
RR cars												X						
Trucks												X						
Sluice or pumped		X	X			X	X	X					X	X		X		
End use of fly ash:																		
Fill or accumulate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dumped in ocean																		
Mineral filler												X						
Abrasive												X						
In asphalt paving 1/												X						
Admixture in concrete 1/												X						
Pozzolanic material 1/																		
Bricks 1/																		
Building blocks 1/																		
Cinder blocks 1/																		
Concrete pipes 1/																		
RR grouting							X											

1/ Quantity used for this purpose represents only a small percentage of the total fly ash collected at plant.

4. BLANKS, ROBERT F. Fly Ash as a Pozzolan. Jour. Am. Concrete Inst., vol. 21, No. 9, May 1950, pp. 701-707.

Fly ash is being used in combination with portland cement in the concrete mix at Hungary Horse Dam because of the benefits derived from its use, including lower cost.

Very fine fly ashes of low carbon content are superior when used as pozzolans. It has been demonstrated that the silica glass, of which fly ash is largely composed, in the presence of water reacts with free lime liberated during hydration of portland cement to form a more stable cementing medium.

Blanks says that a fly ash produced in Illinois combined with portland cement in a proportion of 30 percent fly ash and 70 percent portland cement, by weight, produces a concrete superior to that made from portland cement alone. The fly-ash and portland-cement combination requires slightly less water for a given degree of workability than straight portland cement. Test concrete mixes with up to 50 percent fly ash showed no increase in water requirements over concrete with 100 percent portland cement. Strength tests showed that concretes with 30 percent fly ash and 70 percent portland cement and 40 percent fly ash to 60 percent portland cement were approximately equal in compressive strength to concretes with 100 percent portland cement after

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1 year. Straight portland-cement concrete, however, gains strength faster than the fly-ash mixes.

Blanks further reports that the durability of concrete made with a percentage of fly ash in the mix is improved. The concrete so produced also is less permeable, and the heat of hydration is lower. Tests show that drying shrinkage generally is less than for straight portland-cement concrete. For alkali-aggregate reaction, tests indicate that calcined shale and raw opal are more effective than fly ash in reducing alkali-aggregate reaction, but fly ash is more effective than raw shale, slag, and various other pozzolans.

Numerous graphs showing the conditions described in the text are included in the paper.

5. MINNICK, L. J., and BAUER, W. H. Utilization of Waste Boiler Fly Ash and Slags in the Structural Clay Industry. Am. Ceram. Soc. Bull., vol. 29, No. 5, May 1950, pp. 177-180.

The paper describes various laboratory and field studies of the characteristics and properties of brick made with fly ash and slag without adding clay, and others made with fly ash and clay. The report includes numerous tables and photographs. The fly ash and boiler slag used are products of the combustion of pulverized coal. The fly ash is collected by electrostatic or mechanical means. The slag is removed by being dropped into a stream or pool of water.

The authors report that the brick formed at least equal those produced from clay and shale in the same plant operation. The physical properties of the brick compare favorably with the common commercial brick, it is said.

A previous paper (12) describes some of the earlier results of this work.

6. DAVIS, R. E. Use of Pozzolans in Concrete. Jour. Am. Concrete Inst., vol. 21, No. 5, January 1950, pp. 377-384.

A pozzolan is defined as a siliceous material which, while in itself having no cementitious value, will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide at ordinary temperatures to form insoluble compounds having cementitious properties. The reaction rate depends on the mineral composition and fineness of the pozzolans.

Davis reports that the carbon content of fly ashes ranges from less than 1 percent to over 20 and the silica content from less than 30 percent to more than 45. As a cement replacement, the optimum amount of a pozzolan used may be as low as 4 to 6 percent for fine-ground diatomite to 35 to 50 percent for some fly ashes. Where a pozzolan is used to replace a portion of the portland cement the concretes are generally more plastic, bleed less, and show less segregation than corresponding concretes containing straight portland cement.

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Davis gives figures to substantiate the claim that fly ashes of high fineness and low carbon content are good pozzolans for general concrete construction. Cements in which 25 or 30 percent fly ash is used as a cement replacement have properties of strength, drying, shrinkage, and weathering resistance approximately equal to or superior to the same properties of concretes with straight portland cement.

7. HANDY, WALTER. Use of Fly Ash in Concrete. Fly-Ash Symposium, Am. Soc. Mech. Eng., paper 49-A-81, ann. meeting, 1949.

Handy reports that the history of the use of fly ash in concrete started in Italy about 2,000 years ago. The material used with lime to make masonry was volcanic ash activated by nature and called pozzolana. It is stated that many natural pozzolans, including Italian pozzolana, have been tried with present-day portland cements, and in nearly all tests fly ash has equaled and in some tests been superior to natural pozzolanic cements.

The paper discusses the effect of fly ash on the following properties of concrete: (1) Water requirement; (2) workability, (3) compressive strength; (4) heat of hydration; (5) volume change; (6) resistance to freezing and thawing; and (7) reactive aggregate volume change. It is pointed out that research on the problem is being carried on by industrial organizations and Government agencies.

8. RANDALL, M. C. Some New Developments in the Use of Fly Ash. Fly-Ash Symposium, Am. Soc. Mech. Eng., paper 49-A-83, ann. meeting, 1949.

This paper discusses four uses for fly ash that promise to absorb an appreciable quantity of the material; they are: (1) Insulating cements; (2) building brick; (3) soil-stabilization compound; and (4) fly ash and the foundry industry.

Several tables are given showing the chemical analysis of fly ash collected at different plants and the sieve analysis of the same material.

Randall reports that an insulating cement of good quality was compounded by using fly ash with portland cement and insulating materials. The product had good adhesive qualities and did not shrink when the cement dried.

The paper states that an excellent brick can be manufactured using fly ash and boiler slag. The brick can be produced in standard equipment and is of good quality and appearance. A fly ash containing not over 12 percent carbon is recommended. A table is given in the paper showing the properties of fly ash and slag brick fired at 1,900° F., compared with standard shale brick.

Randall reports, that fly ash mixed with lime can be used as a low-cost cement binder for soil or aggregate material for use under pavements. Other compositions containing fly ash also have been tested with good results.

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Fly ash, according to Randall, is mixed with molding sand in some steel foundries, and, in other nonferrous foundries, it is used to an extent in core work.

9. WALKER, HENRY S. The Present and Future Magnitude of the Pulverized-Coal Fly-Ash-Disposal Problem. Fly Ash Symposium, Am. Soc. Mech. Eng., paper 49-A-79, ann. meeting, 1949.

This paper presents some historical information on the fly-ash disposal problem and some pertinent data on the properties of fly ash. Table 2 gives the range of chemical analyses and physical properties of fly ash collected by 46 public utilities and 8 industrial organizations that reported.

TABLE 2. - Range of analyses and physical properties of fly ash, dried

	Utilities	Industrials
Carbon as C.....percent	0.37 - 36.2	2.4 - 64
Iron as Fe_2O_3 or Fe_3O_4 ..... do.	2.0 - 26.8	10.6 - 43.6
Magnesium as MgO..... do.	.06 - 4.77	.10 - 1.49
Calcium as CaO..... do.	.12 - 14.73	1.92 - 11.8
Aluminum as Al_2O_3..... do.	9.81 - 58.4	10.0 - 21.0
Sulfur as SO_3..... do.	.12 - 24.33	.66 - 28.0
Titanium as TiO_2..... do.	.50 - 2.8	.22 - 3.81
Carbonate as CO_3..... do.	.05 - 2.6	.05
Silicon as SiO_2..... do.	17.3 - 63.6	25.0 - 46.0
Phosphorus as P_2O_5..... do.	.07 - 47.2	.05 - 1.93
Undetermined..... do.	.08 - 18.9	-
Retained on 325-mesh..... do.	8 - 95	26 - 84
Through 325-mesh..... do.	5 - 92	16 - 71
Fusion temperature of ash.....°F.	1,910 - 3,000	1,980 - 2,900
pH value.....	4.7 - 11.7	6.3 - 12
Apparent specific gravity.....	.79 - 3.0	.77 - 1.45

Walker also lists 15 of the more-important attempted commercial uses for fly ash, which have been made over a period of years, with success in a few instances. The principal commercial uses at present are given as replacement of cement in construction concrete in general and such specific things as cinder blocks, bricks, asphalt, and bituminous-road construction. Seventy-nine public utilities, generating about 65 percent of the public utility coal-generated energy, and 24 industrial concerns are reported to collect 2,352,454 tons of fly ash annually. Of this amount only a small portion is disposed of profitably.

10. WEINHEIMER, C. M. The Use of Fly Ash in the Bitumastic Road Industry. Fly Ash Symposium, Am. Soc. Mech. Eng., paper 49-A-82, ann. meeting, 1949.

This paper discusses the use of fly ash in the bituminous-road industry and cites the work of the Detroit Edison Co. in this field, pointing out that in 1939 this company's fly ash was first approved as

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a mineral filler for bituminous-road construction. Table 3 shows the similarity in chemical composition of the Detroit Edison fly ash and Trinidad-asphalt filler. The fly ash is hydrophobic, has good void-filling capacity, and meets the requirements of mineral-filler specifications as to particle-size distribution and moisture content. It is suggested that any company planning to dispose of its fly ash as a mineral filler find out the characteristics of the material at the start; and, if the physical properties and chemical composition are in line with the Detroit Edison product, the fly ash has a good chance of proving satisfactory. It is pointed out that considerable sales effort may be required, even after the fly ash has proved to be satisfactory, before the material is accepted.

TABLE 3. - Chemical composition

	SiO_2, percent by wt.	Al_2O_3, percent by wt.	Fe_2O_3, percent by wt.	Total
Fly ash, as collected.....	45.9	26.9	9.1	81.9
Fly ash, burned free of carbon..	51.4	30.1	10.2	91.7
Trinidad-asphalt filler.....	67.6	18.9	6.4	92.9

11. PIRANI, M., and SMITH W.D. Utilization of Fly Ash. Fuel, vol. 28, No. 4, April 1949, pp. 73-76.

Pirani and Smith describe two methods of utilizing fly ash. One is the manufacture of brick or tile for building purposes. The other use reported is for bitumen-bonded tile.

In preparing brick and tile, the carbon in the ash is first removed by heating the ash at 1,290° F. in air with repeated stirring. The decarbonized fly ash then is mixed with an aqueous solution of sodium or potassium silicate. In this particular case, 100 parts of ash and 20 parts of a solution of 2 parts of waterglass (sp. gr., 1.33) to 18 parts of water were mixed and then pressed at 6 tons per sq. in. to form 2-inch-square tile. After 1 hour, the tile was fired on a bed of coarse carborundum at 2,100° F. for 30 minutes and then allowed to cool in the furnace. The writers point out that the sodium silicate acts as a lubricant and surface conditioner rather than as a binder.

The tile is not slippery and has a metallic ring and a crushing strength of 2,000 to 4,000 lb. per sq. in. The tensile strength is 800 to 1,200 lb. per sq. in., with about an 8-percent shrinkage during sintering. It is stated that glazes can be applied to the tile; however, a high-melting-point glass powder of the pyrex type is advised. Measurements of the dielectric constant and volume resistivity gave results agreeing with known properties of glasses and other ceramics.

A bitumen-bonded tile prepared at the British Coal Utilisation Research Association contained 2 parts flue dust to 1 part Pool Oxidized A2/ bitumen pressed at about 212° F. The product is nonplastic

2/ The sticky residue from petroleum distillation marketed by the Shell Marketing & Refining Co.

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but not very brittle and has a crushing strength of about 600 lb. per sq. in. It is reported that the tile is not affected by heating to 140° F. In these experiments, other binders used included tar oil, pitch, producer tar, hard bitumen, Chatterton compound, and Picein wax.

In preparing the mix the binder was melted at about 300° F. and the flue dust added in small amounts, with constant stirring and heating. When the mixture was of correct proportions, it was removed at about 212° F. to a cold 2-inch-square mold and pressed at 3 tons per sq. in. The product was rather tough and resembled vulcanized rubber tile somewhat. The product can be bonded with rubber cements.

The paper includes tables giving analytical information on different fly ashes and high-melting glasses and volume resistivity of various materials. A graph showing a permittivity to frequency curve and a power factor to frequency curve likewise is a part of the paper.

12. MINNICK, L. J. New Fly-Ash and Boiler-Slag Uses. Tappi, vol. 32, No. 1, January 1949, pp. 21-28.

Minnick point out the difference in chemical composition and physical properties of fly ashes from different locations and produced under different conditions and gives the results of tests on fly ash from three locations in table 4.

TABLE 4. - Fly-ash tests

Analysis of fly ash, percent

	Philadelphia	Newark	Chester
SiO_2	40.32	45.42	34.98
Fe_2O_3	13.39	11.54	13.79
FeO	3.95	3.74	4.96
Al_2O_3	32.92	29.62	27.05
CaO	2.34	1.93	2.85
MgO	.74	.94	.82
Carbon	5.79	4.81	14.84
Specific gravity	2.46	2.53	2.41
Sieve analysis:			
On 60-mesh	2.0	1.5	1.0
Through 60 on 100-mesh	8.0	3.0	5.0
Through 100 on 200-mesh	11.0	11.0	25.0
Through 200-mesh	79.0	84.5	69.0

The author reports there is evidence that high-carbon-content fly ashes do not have as high a pozzolanic reactivity as low-carbon-content material. The amount of soluble salts in fly ash shows considerable

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variation. The pH value also is variable. Petrographic microscope and x-ray-diffraction studies show nearly all of the fly ash is present as a high-melting glass stained with iron.

It is reported that mixtures of fly ash and boiler slag ranging in composition from 80 percent fly ash and 20 percent slag to 40 percent fly ash and 60 percent slag have produced a good brick. Factors, such as grain size of the slag and carbon content of the fly ash, influence the quality of the end product.

Properties of fly-ash - slag brick fired at 1,900° F., compared with standard shale brick, are given in table 5.

TABLE 5. - Comparative properties of brick

	Fly ash-slag brick	Shale brick
Compressive strength.....p.s.i.	6,000-8,000	4,000-8,000
Modulus of rupture..... do.	1,600-1,800	500-2,000
Absorption.....percent	8-10	8-12
Saturation coefficient.....	0.78	0.78-0.90
Color.....	Light to dark red	-
Efflorescence (McBurney).....	None	-
Freezing and thawing (A.S.T.M.).	No breakage or loss in weight after 50 cycles	-
Weatherometer (equivalent to 7 years exposure).....	No breakage or loss in weight	-

Minnick reports that a descumming agent has been developed that eliminates this problem in fly ash-clay brick and may result in use of the mix to a wider extent in the near future.

The paper summarizes the results of various applications that have been made of fly ash as a mix with portland cement. Other uses for fly ash that are under investigation are discussed briefly, as is the handling of the material.

13. ROCK PRODUCTS. Use Fly Ash As Concrete Additive. Vol. 51, No. 10, October 1948, pp. 147-148.

This article describes a three-stop batching plant erected in Chicago for concrete to be poured in foundations, floor slabs, walls, and tunnels of a large power-house installation. At the third weight-batch stop, fly ash is introduced into the mix. It is stated that, by using fly ash, a six-bag mix designed for 3,000 p.s.i. strength in 28 days requires only four bags of cement to obtain the same test strength.

Two different mixes are batched at this job: One of 3,000 p.s.i. compressive strength design, used for caissons; and the other of 3,750 p.s.i. compressive strength, used for floor and wall slabs. Proportions of the mixes, expressed in pounds, are:

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Compressive strength, p.s.i.	Sand	Gravel	Cement	Fly Ash	Water
3,000	2,992.8	3,892.0	752.0	150.4	437.0
3,750	2,824.0	3,816.0	940.0	188.0	454.5

14. THOMPSON, P. W. Stack-Dust Collection and Disposal. Power Plant Eng., vol. 51, No. 10, October 1947, pp. 108-110.

Thompson reports on the experience of the Detroit Edison Co. with electrostatic precipitators and mechanical collectors and disposal of fly ash and cinders. The following uses for fly ash are given and briefly discussed: (1) As a substitute for cement and/or sand in concrete, (2) as an aggregate in cinder concrete, (3) in the manufacture of cement as a clay substitute, (4) as a filler for asphalt products, (5) as a soil amendment for heavy clays, (6) as an inert filler for rubber goods, and (7) as an ingredient for foundry cores.

15. WATSON, H. D. The Disposal of the Fly Ash - M. L. Blocks. Conf. on Pulverized Fuel, under the auspices of the Inst. Fuel, June 1947, pp. 536-542.

Watson discusses development of a building block or slab composed chiefly of fly ash. The moist fly ash is mixed with a small amount of chemicals and cement, and the mix is molded and pressed in a special machine. This product is allowed to mature 28 days before use. The material is reported to be fireproof. The surface can be rough or smooth, and the slabs can be sawed to any shape. Conductivity for sound and heat is low. The material is stronger than lightweight concrete and is not damaged by frost.

Numerous tests on the product are described in the paper, and a table is given of comparative values of M. L. material and various types of concrete.

16. AVERY, WILLIAM M. Fly Ash Teams Up With Portland Cement to Make Better Concrete. Pit and Quarry, vol. 39, May 1947, pp. 157-159.

Avery discusses the advantages of replacing 20 to 30 percent portland cement with fly ash and points out the improvement in strength, surface texture, workability, waterproofing qualities, and reduced cracking and breakage in handling. A graph is given in the paper showing the results of comparative permeability tests of plain concrete and concrete containing fly ash.

17. LEVERETTE, FLOYD C. Fly Ash Successfully Employed by Two Midwestern Producers. Pit and Quarry, vol. 39, December 1946, pp. 135-138.

This article describes the procedure followed in making concrete pipe and concrete slabs using fly ash in the mix. Twenty-five percent fly ash is added to the total amount of cement. Fly ash is credited for the smooth inside and outside surface of the finished product. It is reported that the concrete pipe made at the Blue Island plant

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exceeds the A.S.T.M. minimum strength requirements by 50 percent or more. A minimum of chipped edges and breakage from handling has been observed in cured pipe made with fly ash.

18. HAHN, H. [Industrial Ashes as Binders for Building Materials.] Die Tecknik, vol. 1, 1946, pp. 91-96; Chem. Abs., vol. 41, 1947, col. 7699 (M. Hartenheim).

The abstract points out that in Germany during the war a shortage of binders, such as lime and cement, led to the investigation of the merits of using ashes, especially fly ashes, in place of the binders. Lignite ash with 25 to 30 percent CaO is recommended.

19. LEFTWICH, R. F. New Lightweight Aggregate from Fly Ash. Concrete (Mill section), vol. 54, January 1946, pp. 14-15, 39.

This article describes the lay-out and shows a plan and a sectional view of a plant under construction for manufacturing lightweight aggregate from fly ash and slag. The aggregate is used for making concrete block and concrete brick. In the process, fly ash and crushed slag are sintered, the resultant cake is crushed and graded, and the various sizes are stored in separate bins. The next step is the proportioning of the different sizes of aggregate with the cement in making the concrete masonry products.

20. BARMACK, B. J. Repairing Top Heart Rot of Standing Poles. Electrical World, vol. 122, Dec. 23, 1944, p. 77.

Barmack describes how wood-pole top decay was treated with a paste of pentachlorphinol, fuel oil, and fly ash. Tests made 13 months after treatment showed penetration of the solution into the heartwood. Progress of the decay was halted, it was believed.

21. FREDERICK, HARRY A. Application of Fly Ash for Lean Concrete Mixes. Proc. Am. Soc. Test. Mat., vol. 44, 1944, pp. 810-820.

This paper demonstrates the use of fly ash as a partial substitute for sand and also for cement in lean concrete mixes of two to three bags of cement per cubic yard and water-cement ratio = 15 to 20 gallons per bag.

Frederick discusses the electric utility companies problems of disposing of fly ash when pulverized coal is burned and of improving the design of concrete used as a fill around underground electric-cable duct-line assemblies. A strength of 500 p.s.i. is required for this concrete, as well as extreme workability.

Analyses of the lean mix showed a lack of paste content owing to the low cement factor. To find a solution to this problem and at the same time attempt to find a use for the fly ash, a series of tests was made substituting various amounts of fly ash and other fines in the mix. In all the mixes, however, a standard brand of portland cement was used.

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Table 6 summarizes the results of the chemical and physical tests of the samples of fly ash.

Table 7 summarizes the proportioning, yield, workability, and strength results for the various batches of concrete in the first three series of tests. Results for the series 1 and 2 mixes definitely favor sand replacement by dry fly ash as against replacing any of the cement.

Table 8 summarizes the workability and strength results of plain and fly-ash-concrete mixtures of varying richness. In the fly ash mixes, 25 percent of the normal sand content was replaced by an equivalent amount of dry fly ash No. 174.

Frederick points out that the test results show that fly ash may be substituted for equivalent weights of sand in lean concrete producing a higher-strength product with greater workability than plain concrete. Wet fly ash is not as effective as dry fly ash in producing high early-strength concrete. For a given strength, fly-ash mixes require 34 to 48 percent less cement than plain concrete. Density and surface hardness in fly-ash concretes are superior to plain concretes of equivalent cement content. Strength and workability are not affected detrimentally by high-carbon fly ash when the ash is used as a partial substitute for sand in lean concrete.

22. WEINHEIMER, C. M. Evaluating Importance of the Physical and Chemical Properties of Fly Ash in Creating Commercial Outlets for the Material. Trans. Am. Soc. Mech. Eng., vol. 66, No. 6, August 1944, pp. 551-561.

This paper presents in discussion and tabulation the results of investigational work dealing with the physical and chemical properties and chemical constituents of fly ash. Also, a report is given on the potential sales possibilities of the product and a tabular summary of the results.

The article concludes that only a few industries can use the quantity of ash produced by a large steam-power plant. It points out that the most promising outlets for fly ash are the concrete industry and the bituminous-road industry.

23. SIMON, WALTER, and SPRUNG, HELMUT. Fly Ash from Brown Coal. A Valuable Raw Material. Chem. - Ztg., vol. 67, 1943, pp. 150-3; Chem. Abs., vol. 39, 1945, col. 2392 (B.C.P.A.).

The abstract reports that the fine ash from electrostatic precipitators is a good binder for mortar, plaster, and rough building materials. It can be combined with cement, CaO, or gypsum. If leached with HCl, part of its 15 to 20 percent Al_2O_3 is removed, leaving a residue of bleaching clay.

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TABLE 6. - Chemical and physical tests on fly ash

Date sample received	Sample from Essex Station: Dry fly-ash samples collected at the precipitator				Sample from another utility company	
					Wet fly-ash sample collected at ash pit	Dry fly-ash sample collected at precipitator
	10-17-38	1-20-39	3-8-39	2-27-40	3-27-40	4-26-40
Sample No.	69	82	85	170	172	174
Chemical tests:						
Carbon.....percent	9.90	12.24	6.73	6.51	8.01	14.76
Silica..... do.	41.85	34.20	34.30	36.26	36.35	36.64
Iron oxide..... do.	12.70	12.04	23.72	14.22	16.80	9.30
Aluminum oxide..... do.	29.15	21.80	23.70	28.34	19.25	29.10
Calcium oxide..... do.	3.30	6.02	6.20	4.61	10.70	5.05
Magnesium oxide..... do.		0.67	1.67	0.42	2.21	2.99
Sulfur trioxide..... do.		1.71	2.06	1.23	1.72	0.92
Loss on ignition..... do.		12.60	6.75	7.75	13.61	16.80
Physical tests:						
Specific gravity.....	2.08	2.34	2.41	2.38	2.39	2.36
Unit wt. lb. per cu. ft.:						
Dry loose.....	39.69	42.90	50.50	41.66	40.40	46.08
Dry rodded.....	41.00	46.00	59.96	48.60	45.45	49.87
Voids (loose wt.).....percent	69.2	70.7	66.4	71.9	72.9	68.8
Sieve analysis (dry)..... do.						
Passing No. 16 sieve.....					1/97.0	
Passing No. 50 sieve.....					1/87.0	
Passing No. 100 sieve.....					1/82.0	
Passing No. 200 sieve.....	92.0	92.0	90.0	69.0	78.0	93.8
Passing No. 325 sieve.....	80.0	67.0	42.0	16.0	69.0	75.4
Color.....	slate gray	slate gray	slate gray	light brown	light gray	slate gray

1/ These larger sizes included small pieces of coal.

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TABLE 7. - Summary of test data

Weights of materials in each batch						Test results							
							Workability		Compressive strength, p.s.i.				
Fly ash substituted, percent	Cement, lb.	Fly ash, lb.	Sand, lb.	3/4-in. gravel, lb.	Total water, oz.	Concrete yield of each batch, absolute volume cu. ft.	Slump, in.	Flow, percent	7 day	28 day	90 day	Variation in 7-day strength over plain mix, + = increase - = decrease percent	Remarks
Series 1 - Tests using dry fly-ash sample 85													
Plain mix - no fly ash													
0	4.96	0	26.50	41.30	110	0.5496	2.00	50.70	477	725	837	0	Bleeding.
Sand replaced by fly ash													
5	4.96	1.32	25.18	41.30	110	.5505	6.50	97.80	654	884	974	+ 37	Little bleeding.
10	4.96	2.65	23.85	41.30	110	.5513	7.25	121.90	672	1,008	1,888	+ 41	Very little bleeding.
15	4.96	3.98	22.52	41.30	110	.5520	7.00	109.75	902	1,432	2,118	+ 89	No bleeding.
20	4.96	5.30	21.20	41.30	110	.5528	7.75	116.33	973	1,609	2,100	+104	Fatty.
25	4.96	6.62	19.88	41.30	110	.5536	7.50	62.17	1,017	1,662	2,282	+113	Very fatty.
30	4.96	7.95	18.55	41.30	110	.5544	1.75	32.67	884	1,627	2,728	+ 85	Too stiff.
Series 2 - Cement replaced by fly ash													
5	4.71	.25	26.50	41.30	110	.5500	2.12	38.70	424	654	679	- 11	Bleeding.
10	4.46	.50	26.50	41.30	110	.5503	2.25	55.80	354	601	698	- 26	Do.
15	4.22	.74	26.50	41.30	110	.5507	3.00	22.25	362	530	600	- 24	Do.
20	3.97	.99	26.50	41.30	110	.5511	3.00	40.25	309	575	709	- 35	Do.
25	3.72	1.24	26.50	41.30	110	.5516	3.25	43.08	301	460	785	- 37	Do.
Series 3 - Tests using wet fly ash sample 172 (100 percent sat.)													
Plain mix - no fly ash													
0	4.96	0	26.50	41.30	110	.5496	2.00	66.60	477	760	833	0	Do.
Sand replaced by fly ash													
5	4.96	1.98	25.18	41.30	110	.5505	6.75	105.83	460	760	1,000	- 4	Do.
10	4.96	3.97	23.85	41.30	110	.5513	7.00	143.30	460	822	1,730	- 4	Little bleeding.
15	4.96	5.97	22.52	41.30	110	.5520	8.00	138.75	584	1,008	1,686	+ 22	Very little bleeding.
20	4.96	7.95	21.20	41.30	110	.5528	7.50	120.10	628	1,149	1,818	+ 32	No bleeding.
25	4.96	9.93	19.88	41.30	110	.5536	7.00	95.00	619	1,132	1,922	+ 30	Fatty.
30	4.96	11.93	18.55	41.30	110	.5544	5.25	95.00	601	1,167	2,048	+ 26	Very fatty.

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TABLE 8. - Workability and strength results

Water: cement ratio	Bags cement per yd.	Slump, in.	Flow, percent	Compressive strength, p.s.i. 7-day	28-day
		Plain mixes			
0.916	4.18	7.50	131.7	1,539	1,910
1.177	3.43	7.50	143.4	911	1,203
1.367	2.78	6.25	96.6	725	
1.965	2.06	2.25	36.7	274	477
		Fly-ash mixes			
1.111	3.97	7.50	95.0	2,096	3,484
1.315	3.32	7.50	101.6	1,450	2,653
1.692	2.45	8.75	125.0	831	1,698
2.061	2.02	7.50	120.0	566	1,052
2.835	1.42	7.50	100.0	354	610

24. COLEMAN, S. H. Fly-Ash Blast Cleans Metal Surfaces. Power, vol. 87, January 1943, p. 50.

Coleman points out that, in cleaning some metal surfaces, the abrasiveness of sand is objectionable and says that recent investigations have pointed to the use of fly ash as a substitute for sand where metal losses must be held to a minimum.

25. KRONSTEIN, W. [Fly Ash as Hydraulic Addition for Mortar and Concrete.] Zement, vol. 30, 1941, pp. 503-6, 518-20; Chem. Abs. vol. 36, 1942, col. 2109, F. Held.

The abstract reports that fly ash with less than 2.5 percent SO_3 is a useful addition for mortar and concrete. The time required for hardening is longer than with portland cement, but, after a year, it equals or exceeds the strength of portland cement.

26. NELLES, J. S. Concrete Exposed to Sulfur Water. Jour. Am. Concrete Inst., vol. 12, February 1941, pp. 441-452.

This article reports that test samples of concrete made with some fly ash used in the mix have held up satisfactorily.

Nelles discusses the performance of numerous test samples of different concrete mixes exposed to sulfur water and reports that the condition of the samples in which fly ash was used in place of some of the portland cement compares favorably with the better mixes tested.

27. DAVIS, R. E., DAVIS, H. E., and KELLY, J. W. Weathering Resistance of Concretes Containing Fly-Ash Cements. Jour. Am. Concrete Inst., vol. 12, January 1941, pp. 281-293.

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This investigation was designed to obtain information on the following points: (1) The effect of carbon content alone; (2) the effect of high carbon content on the weathering resistance of concrete; and (3) the reaction of fly ash of relatively high carbon content when used in small percentages of replacement.

Eleven fly ashes of widely different carbon content and fineness were obtained from 10 different sources. The portland cement with which the fly ashes were blended for test was of the modified or moderate-heat-of-hardening type, the investigators report. Table 9 gives the results of the tests on pastes and mortars.

Test results show that no single characteristic controls the performance of a fly ash in concrete. From these tests it appears that fly ashes of fairly high carbon content but of reasonably high fineness may be used in small percentages as replacement for portland cement with good results. Under proper conditions of curing and normal conditions of exposure, improvement in quality, particularly of weathering resistance, can be expected.

27a. NELLES, J. S. Discussion of Davis, Davis, and Kelly paper on Weathering Resistance of Concretes Containing Fly-Ash Cements. Jour. Am. Concrete Inst., vol. 12, June 1941, pp. 296-1 and 296-2.

This discussion advocates additional experimentation on the use of fly ash to replace part of the fine aggregate as well as part of the cement. An example of results of such a mix is given below:

Cement content, bag per cu. yd.	Water-cement ratio, gal. per bag	Fly ash			Compressive strength p.s.i.		
		Replacing cement, pound	Replacing fine aggregate, pound	Total, pound	28 days	3 months	6 months
7	4.8	0	0	0	4,765	5,715	6,585
6	6.0	100	200	300	5,500	7,055	7,435

It is pointed out that the ever-increasing demand for more fines in fine aggregate presents an outlet for fly ash because the extra fines cannot be found in the natural or manufactured sands.

28. ELMER, N. W. Profitable Fly-Ash Handling. Steel, vol. 106, February 12, 1940, pp. 64, 65, and 79.

By using an airtight conveying system, which permits the vacuum on electrostatic-precipitator units to be maintained, fly ash is reclaimed and sold at a profit, the article states. The electrostatic precipitators used are of the graded-resistance concrete-plate type.

In addition to a saving in the cost of cement resulting from the use of fly ash in the mix, Elmer points out the greater strength of the concrete and discusses the chemical reaction of the fly ash in the mix.

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TABLE 9. - Fly-ash cement-paste and mortar tests

Fly ash			Fly-ash cement		Neat paste[1]				Standard mortar; tensile strength (p.s.i. briquets)		
					Normal cons., percent water by wt.	Time of setting, hr. : min. (Gillmore)		Autoclave expansion, percent	7 Days	28 Days	6 Months
Name	Carbon, percent	Spec. surf., sq.cm.gm.	Fly ash percent	Spec. surf. sq.cm.gm.		Initial	Final				
1	2	3	4	5	6	7	8	9	10	11	12
-	-	-	0	2/2,360	23.5	1:30	2:35	0.062	350	420	390
Commonwealth Edison.....	1	5,530	10	2,680	23.4	2:00	3:05	-	345	405	460
			20	2,990	23.3	2:05	3:20	0.034	345	435	485
Chicago.....	2	4,150	10	2,540	22.7	1:40	2:45	-	370	430	460
			20	2,720	22.8	2:10	3:30	0.030	350	415	495
Duquesne.....	7	2,700	10	2,390	24.5	1:40	2:35	-	315	395	460
			20	2,430	26.5	1:50	2:50	0.031	295	395	470
Rochester A.....	8	3,850	10	2,510	25.0	1:35	2:45	-	350	435	475
			20	2,660	27.0	2:05	3:20	0.022	315	410	505
Dayton.....	9	2,980	10	2,420	25.0	2:00	3:10	-	365	415	460
			20	2,480	27.0	2:05	3:05	0.011	305	400	505
Detroit.....	12	3,220	10	2,450	25.5	1:45	2:45	-	350	430	495
			20	2,530	27.5	2:05	3:05	0.018	315	425	505
Philadelphia.....	12	2,920	10	2,420	24.6	1:40	2:45	-	365	415	465
			20	2,470	26.0	2:05	3:05	0.015	310	385	440
Newark.....	13	4,980	10	2,620	25.0	1:55	2:45	-	340	410	490
			20	2,880	26.5	2:25	3:25	0.025	310	395	480
Rochester B.....	14	4,240	10	2,550	26.0	1:55	3:05	-	340	435	490
			20	2,740	28.5	2:20	3:45	0.020	335	415	515
Consolidated Edison.....	16	2,470	10	2,370	26.2	1:50	2:45	-	305	375	420
			20	2,380	28.5	2:35	3:50	0.026	300	390	465
Indiana.....	17	3,920	10	2,520	24.5	1:45	2:50	-	360	415	455
			20	2,670	25.7	2:05	3:15	0.037	305	395	495
Ave. for 11 fly ashes.....	10	3,720	10	2,500	24.8	1:50	2:50	-	345	415	465
			20	2,630	26.3	2:10	3:20	0.024	315	405	485

1/ All cements sound in standard steam test on neat-cement pat.
2/ On A.S.T.M. basis, 2,180 sq. cm. per gram.

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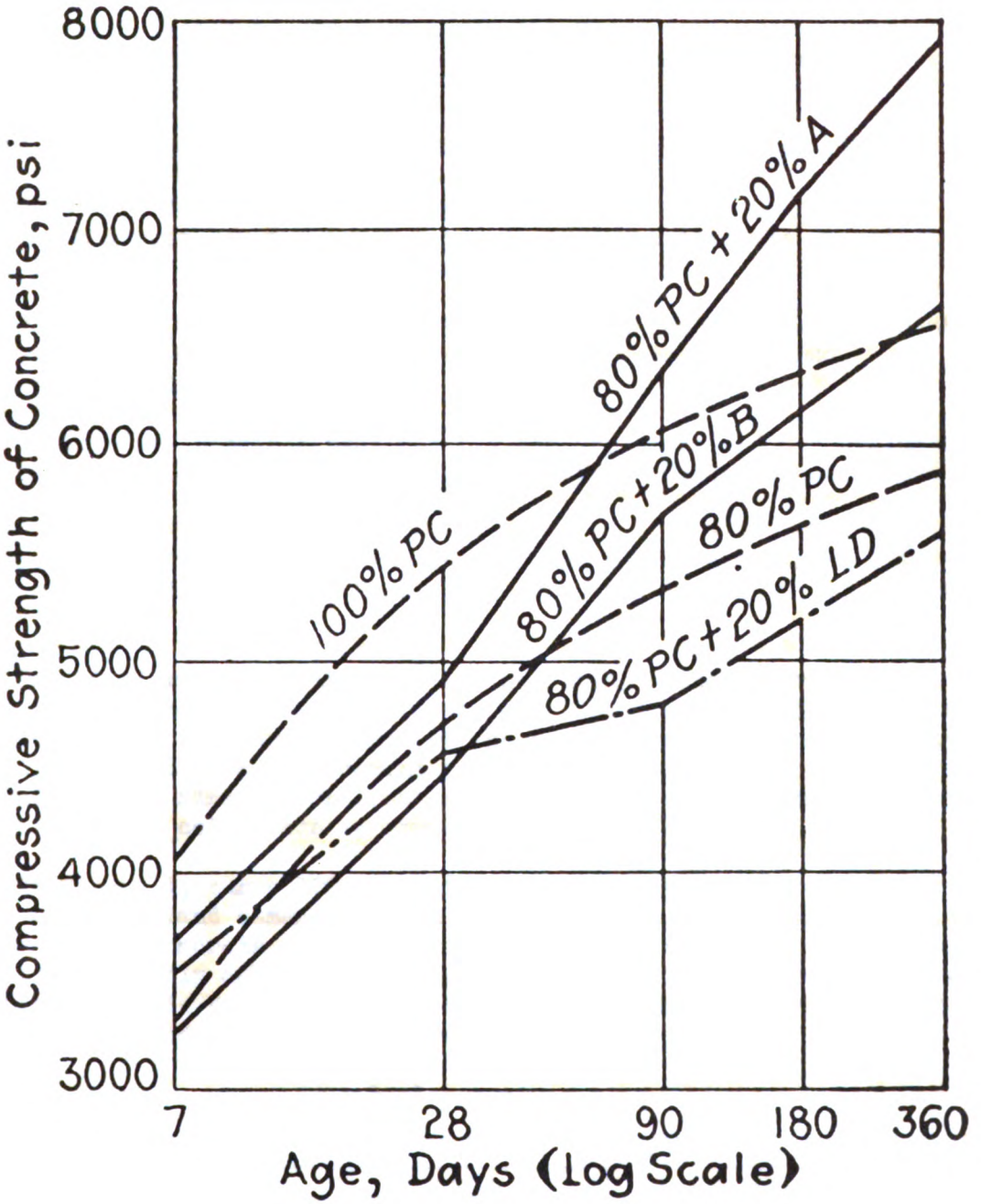

Figure 1. - Strength of concretes.

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29. RAMSEYER, C. F. Solving the Fly-Ash Problem. Elec. Light and Power, vol. 17, February 1939, pp. 44-47, 66.

Ramseyer discusses some of the work that has been done on the utilization of fly ash. Economic aspects of the problem are presented. The characteristics required of a fly ash for use as a pozzolanic material are discussed as are the operating methods necessary to produce a suitable fly ash.

30. POWER. Fuel Beds and Fly Ash. Vol. 82, December 1938, p. 768.

This article discusses briefly the Detroit Edison Co. work in seeking a market for fly ash and tabularly summarizes the investigation listing the possible uses for fly ash.

31. THORSON, A. W., and NELLES, JOHN S. Possibilities of Utilization of Pulverized-Coal Ash. Mech. Eng., vol. 60, November 1938, pp. 845-851.

Twenty-five possible uses for fly ash are described and evaluated. The paper includes numerous tables and graphs. Table 10 summarizes the results of the investigation.

31a. DAVIS, R. E. Discussion of the Thorson and Nelles Article on Pulverized-Coal-Ash Utilization. Mech. Eng., vol. 61, June 1939, pp. 475 and 476.

Principal variables that affect the strength and other properties of portland-cement fly-ash concretes are listed as: (1) The fineness of fly ash; (2) the carbon content of the fly ash; and (3) the percentage of fly ash used as a replacement for portland cement. To obtain a fly ash of greater fineness or greater specific surface the importance of efficient dust collectors is stressed.

In figure 1, curve 100 percent PC shows the strength of concrete made with portland cement containing no fly ash. Other curves show strengths of concrete with 20 percent of cement replaced, respectively, by fly ash A, fly ash B, and limestone dust (an inert material). Curve 80 percent PC is for concrete having the same amount of cement as those with fly ash and limestone-dust replacements.

Replacements

	Fineness		
	Percent passing -		Specific surface,
	200-mesh	300-mesh	sq.cm. per gr.
A - fly ash.....	95.6	90.5	3,220
B - fly ash.....	94.9	90.0	2,460
LD - limestone dust.....	95.5	92.3	4,240

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TABLE 10. - Summary of possible uses for fly ash

Product	Use	Material replaced	Cost of material replaced, $ per ton	Type of investigation[1]	Extent of investigation[2]	Results[3]	Remarks
1. Sheet asphalt....	Filler.	Limestone or silica dust.	3.00	L and F	T	E	Local plants unsuited to fine material.
2. Do.	do.	Portland cement	7.50	F	T	E	Small quantity used.
3. Fertilizer.....	do.	Foundry sand.	Cartage	L	P	-	Replaced material too cheap.
4. Rubber.....	do.	Fuller's earth.	8.00-12.00	P	P	P	Too coarse and gritty.
5. Primer paint....	do.	Calcium carbonate.	20.00	L and P	P	G	Small local market.
6. Putty.....	do.	do.	20.00	L	P	G	Do.
7. Roofing material.	do.	Limestone or silica dust.	3.00	-	-	-	No local market.
8. Common brick.....	do.	Clay.	0.25-0.50	P	T	P	Weak structure.
9. Cinder block.....	do.	-	-	P	T	G	Waterproofs surface.
10. Sand-lime brick..	Aggregate.	Sand.	0.75	P	T	P	Equipment unsuited to fine material.
11. Aerocrete.....	do.	do.	0.75	L	P	P	Poor concrete; small market.
12. Lightweight concrete tile..	do.	do.	0.75	P	T	P	Machine not commercially available.
13. Acoustic plaster.	do.	Pumice.	20.00	-	P	P	Color objectionable; application more important than material.
14. Haydite concrete	do.	Haydite.	8.00	L and P	T	G	Expensive product; small market.
15. Cottrell block...	Aggregate and binder.	Pulverized shale.	-	L and P	T	E	Active project.
16. Sodium-silicate block.....	Aggregate.	-	-	L	T	P	Expensive and unsatisfactory.
17. Pebble concrete..	Admixture.	Portland cement.	7.50	L	T	G	Reduced heat of hydration.
18. Portland cement..	Raw material.	Clay.	0.25-0.50	L and P	T	G	Raised coal consumption.
19. Brick.....	Dusting.	Sand.	0.75	P	T	P	Stuck in molds.
20. Petroleum.....	Color filter.	Fuller's earth.	8.00-12.00	L	P	P	Small market.
21. Foundry.....	Dusting and sand.	Sand.	0.75	P	T	P	Do.
22. Metal.....	Polisher.	Pumice.	20.00	L	P	P	Not abrasive enough.
23. Cinder concrete..	Sintered aggregate.	Cinders.	-	L	T	G	Too expensive.
24. Fly-ash cinder concrete.....	Aggregate.	Sand.	0.75	L and F	T	E	Active project.
25. Sand blasting....	Condenser tubes and turbine blades.	do.	0.75	P	-	E	Gives high polish and low metal loss.

1/ F = field, L = laboratory, P = plant.
2/ P = preliminary, T = thorough.
3/ E = excellent. G = good, P = poor.

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31b. JAMES, J. R. Discussion of the Thorson and Nelles Article on Pulverized-Coal-Ash Utilization. Mech. Eng., vol. 61, June 1939, pp. 476 and 477.

The advantages of Cottrell blocks made from fly ash are enumerated as: (1) Smooth surface, (2) light weight, (3) easily cut with a carborundum saw, (4) fire resistant, and (5) readily painted and plastered.

32. McMILLAN, F. R. and POWERS, T. C. Classification of Admixtures as to Pozzolanic Effect by Means of Compressive Strength of Concrete. Jour. Am. Concrete Inst., vol. 9, November-December 1937, pp. 129-143.

This paper presents a study of the effect of different quantities of admixture on the compressive strength of concrete of a fixed cement content. All the data, with the exception of strengths at 6 months for the precipitator ash, appeared in a previous paper.3/ Numerous graphs show the compressive strengths at 7 and 28 days and at 6 months of moist-cured concretes containing a fixed quantity of portland cement and varying amounts of admixture.

Pozzolanas are defined as those materials that are not cementitious by themselves but have the ability to combine with calcium hydroxide liberated in the cement to form cementitious products. Under favorable conditions, this reaction may be manifested by a change in hardness of strength of the mortar or concrete in which it occurs. The authors point out that, as far as the use of such material in concrete is concerned, not only the chemical effect but also the physical effect must be considered. To determine a pozzolan's usefulness in concrete, it is necessary to know, in addition to the chemical activity, how much can be included in a mixture without materially increasing the water content of the concrete.

In table 11, mixes containing admixtures are compared with plain mixtures having the same 7-day strength. You will note a marked increase in strength of the admixtures after 7 days, as compared with the plain mix.

Note: In the table presented in the paper, a second group of materials showing little or no pozzolanic action after 7 days are also listed. These are not included in table 11 because no fly ashes are listed among them.

3/ Jour. Am. Concrete Inst., March-April 1934, Proc., vol. 30, p. 325.

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TABLE 11. - Comparison of mixes containing admixtures with plain mixtures having the same 7-day strength

Based on concrete moist-cured entire time

Name of admixture	Admixture, lb. per cu. yd.	4-sack concrete: See note	4-sack concrete: Compressive strength, lb. per sq. in. 7 days	28 days	6 months	5-sack concrete: See note	5-sack concrete: Compressive strength, lb. per sq. in. 7 days	28 days	6 months
Group 1 - Pozzolanic action after 7 days									
Precipitator ash 11893 1/	100		2,450	4,250	6,700		3,400	5,350	7,800
Plain mix	0	4.65	2,450	4,000	5,400	5.55	3,400	5,050	6,900
Precipitator ash 11893 1/	200		2,800	5,000	7,500		3,500	5,750	8,350
Plain mix	0	5.10	2,800	4,400	6,050	5.65	3,500	5,150	7,000
Precipitator ash 11897 1/	100		2,200	3,900	6,000		3,200	5,050	7,200
Plain mix	0	4.40	2,200	3,650	5,000	5.35	3,200	4,850	6,600
Precipitator ash 11897 1/	200		2,250	4,100	6,600		3,100	5,000	7,400
Plain mix	0	4.50	2,250	3,700	5,100	5.25	3,100	4,750	6,450
California Pumicite	100		1,700	2,950	4,900		2,500	4,000	6,100
Plain mix	0	4.35	1,700	2,750	4,050	5.10	2,500	3,800	5,300

Note: The figures in this column indicate the sacks of cement per cubic yard in the plain mix having equal 7-day strengths.

1/ The precipitator ash was used with a different lot of cement, testing in a 4-sack mix about 350 lb. higher at 7 days; and 800 lb. higher at 6 months than that used with the other materials shown in the table.

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32a. DERLETH, C. P. Discussion of Paper by McMillan and Powers, Classification of Admixtures as to Pozzolanic Effect by Means of Compressive Strength of Concrete. Jour. Am. Concrete Inst. vol. 9, March-April 1938, pp. 144-1, - 144-4.

In the discussion, the advisability of designating the ash from the combustion of pulverized coal as fly ash rather than precipitator ash or some other term in the interest of clarity and conformity is suggested.

Derleth points out that cement-water paste generally is regarded as the workability medium in portland-cement concrete. Other conditions being unchanged, a reduction in paste volume also reduces workability. An equal volume of paste made of cement with a reasonable proportion of Colloy fly ash as a replacement and containing an equal weight of the blend will contain less water than the corresponding straight cement-water paste because the fly ash has a lower specific gravity than ordinary cement. Tests show that water, known to increase workability, can be reduced substantially when reasonable weights of the usual cement are replaced with fly ash.

33. JAMES, J. R. Utilization of Pulverized-Fuel Fly Ash. Trans. Am. Soc. of Mech. Eng., vol. 59, FSP-59-10, 1937, p. 370.

James reports on the successful use of fly ash in developing a new kind of concrete and a building material called Cottrell block. Figures are included giving the compressive strength and proportions of the ingredients in the new concrete and the heat-conductivity coefficient for an 8-inch wall of the Cottrell block.

34. DAVIS, R. E., CARLSON, R. W., KELLY, J. W., and DAVIS, H. E. Properties of Cements and Concretes Containing Fly Ash. Jour. Am. Concrete Inst., vol. 8, May-June 1937, pp. 577-612.

The results of numerous tests to determine the effect of using fly ash as a replacement for portland cement upon the properties of mortars and concretes are presented. The tests included fly ashes from 15 different sources, blended in percentages up to 50 with portland cement of seven compositions, and results reported on mixes up to the age of 1 year. In the paper, much of the test data are presented in tabular form.

It is reported that the fly ashes were from widely scattered coal deposits. However, the chemical composition did not differ greatly, except in the case of the carbon content. The fly ashes on the whole were much finer than portland cements; and, in certain fly ashes, many of the particles were spherical. In general, fly ashes show high pozzolanic activity with the finer fly ash, with low carbon content showing the greater activity and the greater contribution to the strength of mortars and concretes. Under normal conditions of moist curing, about 30 percent of portland cement can be replaced by fly ash of high fineness and low carbon content. For

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conditions of curing normal for mass concrete fly ashes of similar fineness and carbon content, it is reported that a 50 percent replacement by fly ash appears advantageous.

The paper further states that, on the whole, the results obtained by simply admixing the fly ash with the portland cement are as good as, or better than, those obtained by intergrinding the two materials. Fly ash cements set more slowly than portland cements, but the times are usually within the specification limits.

34a. DERLETH, C. P. Discussion of Paper by Davis, Carlson, Kelly, and Davis, Properties of Cements and Concretes Containing Fly Ash. Jour. Am. Concrete Inst., vol. 8, September-October 1937, pp. 612-1 - 612-4.

In this discussion, issue is taken with the statement in the summary of the main paper that, "concretes containing properly constituted fly ash cements exhibit about the same water requirement to produce a given consistence." It contends the test evidence indicates that less water is required. Derleth says the paper infers that no constituent of a pozzolana other than silica is reactive with lime, although actually other authorities have conclusively confirmed by tests that alumina in pozzolanas is reactive with lime in the formation of mono-calcium aluminate.

The author states that no single percentage of any blending medium is the optimum for all classes of work involving different conditions of placing, various early service and ultimate strength requirements, and conditions of exposure. He suggests the desirability of separate standards relating to the grade of pozzolans and other blending media in preference to a standard fixing the grade of blended cements.

As compared with unblended portland cement, Derleth says that fly ash gives greater absolute volume, and, used as a blend to replace percentages by weight gives the effect of a richer mix; greater fineness giving the equivalent of a finer cement and the spheroidal particles reducing friction at the aggregate interfaces, all contributing to increased workability. He contends that the combined effect of these conditions is a reduction in the amount of mixing water of usually 2 to 5 gallons per cubic yard of concrete.

35. PILCHER, J. M., and VILBRANDT, F. C. Humid Aging of Fly-Ash Brick. Ind. Eng. Chem., vol. 29, No. 4, April 1937, pp. 427 and 428.

Pilcher and Vilbrandt report that tests on fly ash bricks showed that the addition of rosin is unnecessary when the bricks are humid-aged. The molding pressure applied for 1 week on humid-aged brick can be considerably less it is said than that required for atmospheric-aged brick to produce a product of comparable compressive strength. Humid-aged brick showed increased compressive strength when the aging period was of longer duration.

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36. HARRISON, R. L., JONES, P. W., and SHREVE, R. N. Rostone Operations. Ind. Eng. Chem., vol. 27, No. 9, September 1935, pp. 1023-1026.

This article discusses the composition and characteristics of a building material called Rostone made largely from fly ash and briefly describes a new plant for manufacturing the product. In production a reaction between fly ash and an alkaline-earth base is used. The fly ash constitutes approximately 90 percent of the finished product.

The percent chemical composition of two samples of fly ash are given as:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO	C
Sample A.....	46.9	29.9	11.9	2.6	0.9	1.3	6.5
Sample B.....	44.10	20.44	18.72	6.85	.92	.71	8.26

When enough quicklime is present in the fly ash to cause unsoundness in the finished product, the article states that the fly ash must be slaked. The fly ash as received or as slaked and tempered is mixed in a wet pan with the proper proportion of slaked hydrated lime and pulverized wood rosin. The latter is added to prevent efflorescence. A typical mixture by weight is 100 parts fly ash, 10 hydrated lime (high calcium), 0.5 wood rosin, and 19 water.

After the damp mass is mixed it is pressed by about 2,500 pounds per square inch pressure or tamped under pressure in the desired shapes. The material is then subjected to saturated steam for 2 hours at 75 pounds pressure. In this period, the chemical reaction between the fly ash and the hydrated lime takes place to form a dense, hard, stonelike mass.

A change in color of the finished product from the usual slate gray or grayish black can be made by heating the fly ash under oxidizing conditions from 700° to 1,000° F. The carbon is burned out and the magnetite changed.

The finished product has a smooth surface, no warpage or shrinkage occurs, and brick of fly ash have the following physical properties:

Compressive strength (2-inch cubes)	6,000 - 8,000 lb. per sq. in.
Modulus of rupture (standard brick test)	600 - 1,000 lb. per sq. in.
Absorption (5-hour immersion)	3.5 - 6.0 percent

37. MENZEL, C. A. Strength and Volume Change of Steam-Cured Portland Cement Mortar and Concrete. Jour. Am. Concrete Inst., vol. 6, November-December 1934, pp. 125-148.

This is a report of an investigation made at the Research Laboratory of the Portland Cement Association, Chicago, to obtain data on the strength and volume changes of cement pastes and mortars, mixtures of cement and finely divided silica and mixtures of cement and silica bearing materials,

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one of which was flue ash. Various percentages of the silica or silica-bearing material were used in the mixtures. Some neat and mortar specimens of each mix were cured in saturated steam at high temperatures for different periods of time, other specimens were moist-cured. The results of the strength tests showed that the mixtures containing the flue ash compared favorably with mixtures containing other silica-bearing materials. The volume tests also showed the mixtures containing flue ash in favorable light when compared with the other silica-bearing mixtures.

The report includes many curves showing the comparative merits of the different specimens tested. The appendix includes a table giving the chemical composition of the materials used.

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